# 5. CIRCULATING PFBC, SECOND GENERATION, BOOSTED

## 5.1 INTRODUCTION

This circulating pressurized fluid bed combustor (CPFBC) concept utilizes a carbonizer to produce a syngas from volatiles in the coal. The syngas is combusted in the topping combustor of a state-of-the-art combustion turbine, derived from the Westinghouse 501G technology class.

The CPFBC portion of the plant is comprised of a single train of process vessels, including one each of a carbonizer, pressurized fluid bed combustor, and fluid bed heat exchanger. Multiple vessels are used for cyclones and ceramic candle filter vessels, which remove particulates from the gas path.

The resulting plant produces a net output of 379 MWe at a net efficiency of 47 percent, on an HHV basis.

## 5.2 HEAT AND MASS BALANCE

This CPFBC power plant utilizes a combined cycle for conversion of thermal energy from the fluid bed to electric power. An open Brayton cycle using air and combustion products as working fluid is used in conjunction with the existing conventional subcritical steam Rankine cycle. The two cycles are coupled by generation of steam in the fluidized bed heat exchanger (FBHE) and in the heat recovery steam generator (HRSG), and by heating feedwater in the HRSG.

The gas turbine operates in an open cycle mode, with alterations to the cycle originally established for the W501G class machine. The inlet air is compressed in a single spool compressor to the design basis discharge pressure. Instead of passing directly on to the burner assembly as in a standard “G” machine, most of the air is removed from the machine and conveyed to the CPFBC island, where it is divided into several streams. A small portion of the air (5 percent) is boosted to a higher pressure (385 psig) for use in the lock hopper injection system for fuel and sorbent. Another small stream (9.5 percent) is boosted to 335 psig for induction into the carbonizer, where it facilitates the coal devolatilization and pyrolysis process. An additional stream (approximately 24 percent) is retained at the machine and used internally for turbine cooling air, and for cooling of the multi-annular swirl burner (MASB) assemblies. The remaining air removed from the machine is sent to the CPFB combustor area.

The main air stream removed from the machine is compressed in a motor-driven boost compressor by a nominal 32 psi or 12 percent increase. The boosted air then is sent to the CPFBC vessel and the accompanying FBHE to provide $O_2$ for combustion reactions and fluid momentum for material transport. The carbonizer and lock hopper air streams are boosted by separate compressors.

The cleaned hot gas from the CPFBC is returned to the gas turbine, along with low-Btu fuel/gas from the carbonizer. These two streams are mixed and combusted in an MASB topping combustor, which is comprised of a number of combustion chambers that are mounted external to the original gas turbine machine envelope. The gas turbine used in this application requires significant structural and flow path modifications and is thus considered a derivative of the 501G machine, and not an actual production model.

The hot combustion gases are conveyed to the inlet of the turbine section of the machine, where they enter and expand through the turbine to produce power to drive the compressor and electric generator. The turbine exhaust gases are discharged through a HRSG to recover the large quantities of available thermal energy. The HRSG exhausts to the plant stack.

The Rankine steam power cycle is shown schematically in the 100 percent load Heat and Mass Balance diagram, Figure 5-1. Overall performance for the entire plant, including Brayton and Rankine cycles, is summarized in Table 5-1, which includes auxiliary power requirements. The net plant output, after plant auxiliary power requirements are deducted, is 379 MWe. The overall net plant efficiency is 47 percent, based on HHV of the fuel.

The steam generation in the FBHE and in the HRSG is matched to the steam conditions established for this design. The Rankine cycle used herein is based on a 2400 psig/1050°F/1050°F single reheat configuration. The HP turbine uses 1,037,486 lb/hour steam at 2400 psig and 1050°F. The cold reheat flow from the HP turbine to the reheater in the FBHE is 991,293 lb/hour of steam at 510 psig and 657°F, which is reheated to 1050°F before entering the IP turbine section.

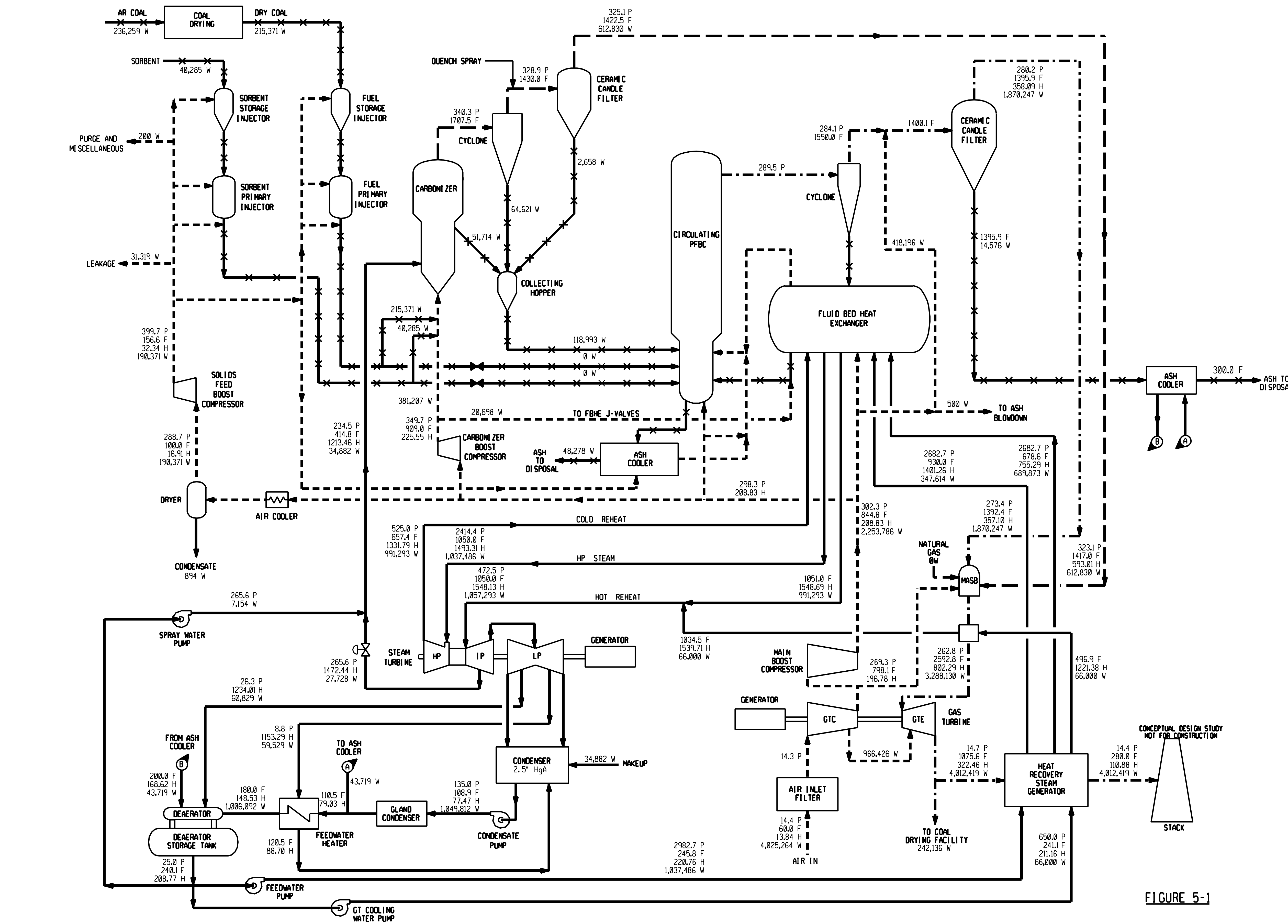


FIGURE 5-1

NOTES:

1. ENTHALPY REFERENCE POINT IS NATURAL STATE AT 32.018°F AND 0.08865 PSIA.
2. BOOST COMPRESSORS ARE MOTOR DRIVEN.
3. STEAM LEAKAGE AND BLOWDOWN MODELED BUT NOT SHOWN.

**LEGEND**

- AIR
- FUEL GAS
- COMBUSTION PRODUCTS/VITIATED AIR
- SOLIDS
- WATER / STEAM
- P ABSOLUTE PRESSURE, PSIA
- F TEMPERATURE, °F
- H ENTHALPY, Btu/LB
- W TOTAL PLANT FLOW, LB/HR
- MWe POWER, MEGAWATTS ELECTRICAL

**SYSTEM PERFORMANCE SUMMARY**

| | |
|---|---|
| GAS TURBINE POWER : | 210.894 MWe |
| STEAM TURBINE POWER : | 198.915 MWe |
| GENERATOR LOSS : | 8.035 MWe |
| AUXILIARY POWER (TOTAL) : | 22.590 MWe |
| NET PLANT POWER : | 379.184 MWe |
| NET PLANT EFFICIENCY : | 47.0 % HHV |
| NET PLANT HEAT RATE : | 7,269 Btu/kWh HHV |

REV | DATE | DESCRIPTION | DRAWN | CHECKED | LEAD DESIGNER | ENGINEER | LEAD DISCP ENGINEER | PROJ ENGR MANAGER | PROJECT MANAGER

STATUS OF DRAWING: PRELIMINARY — DEFINITION: REPRESENTS GENERAL DESIGN CONCEPTS BASED ON ASSUMPTIONS. REVIEWED NOT CHECKED.

CONSTRUCTION STATUS

DRAWN BY: CLB DATE

CHECKED BY DATE

LEAD DESIGNER DATE

ENGINEER DATE

LEAD DISCIPLINE ENGR. DATE

PROJECT ENGINEERING MANAGER

PROJECT MANAGER

PARSONS
PARSONS POWER GROUP INC.
READING / BOSTON / CHARLOTTE / CHATTANOOGA

CLIENT/PROJECT TITLE
CLEAN COAL TECHNOLOGY PROGRAM
CPFBC REFERENCE PLANT
DEPARTMENT OF ENERGY

HEAT AND MASS BALANCE DIAGRAM
MAXIMUM EFFICIENCY CASE TASK 22

SCALE NONE

PARSON'S DWG. NO. MBAC-1-400-314-006 REV A

ARCH | HVAC | I & C | ELECT | MECH | CIVIL | STRUC

432006:40031406.GRA
432006:40031406.DGN

**Reserved for reverse side of Figure 5-1 (11x17)**

**Table 5-1**
**PLANT PERFORMANCE SUMMARY - 100 PERCENT LOAD**

(Loads are presented for one CPFB package, one gas turbine, and one steam turbine)

| | |
|---|---|
| STEAM CYCLE | |
| Throttle Pressure, psig | 2,400 |
| Throttle Temperature, °F | 1,050 |
| Reheat Outlet Temperature, °F | 1,050 |
| POWER SUMMARY (Gross Power at Generator Terminals, kWe) | |
| Gas Turbine | 206,759 |
| Steam Turbine | 195,015 |
| Total | 401,774 |
| AUXILIARY LOAD SUMMARY, kWe | |
| Coal Handling | 150 |
| Coal Drying and Crushing | 1,400 |
| Limestone Handling & Preparation | 450 |
| Transport Booster Compressor | 880 |
| Carbonizer Booster Compressor | 2,010 |
| Main Boost Compressor | 8,130 |
| Condensate Pumps | 160 |
| Main Feed Pump | 3,720 |
| Boiler Forced Circulation Pump | 100 |
| Miscellaneous Balance of Plant (Note 1) | 900 |
| Gas Turbine Auxiliaries | 400 |
| Steam Turbine Auxiliaries | 300 |
| Circulating Water Pumps | 1,620 |
| Cooling Tower Fans | 900 |
| Ash Handling | 80 |
| Soot Blowers (Note 2) | 0 |
| Transformer Loss | 1,390 |
| TOTAL AUXILIARIES, kWe | 22,590 |
| Net Power, kWe | 379,184 |
| Net Efficiency, % HHV | 47 |
| Net Heat Rate, Btu/kWh (HHV) | 7,269 |
| CONDENSER COOLING DUTY, $10^6$ Btu/h | 1,000 |
| CONSUMABLES | |
| As-Received Coal Feed, lb/h | 236,260 |
| Sorbent, lb/h | 40,285 |

Note 1 **-** Includes plant control systems, lighting, HVAC, etc.

Note 2 **-** Soot blowing medium is steam. Electric power consumption is negligible.

The steam turbine selected to match this cycle is a two-casing, reheat, double-flow exhaust machine. The HP and IP turbine sections are contained in one casing, with the LP section in another casing. The turbine runs at 3,600 rpm, and drives a hydrogen-cooled generator. The LP turbine exhausts to a single-pressure condenser operating at 2.0 inches Hga at the nominal 100 percent load design point. For each LP turbine, the last-stage bucket length is 30.0 inches, the pitch diameter is 85 inches, and the annulus area per end is 55.6 square feet.

The condensate and feedwater heating is accomplished by heat recovery from the gas turbine exhaust, in the HRSG. A deaerating heater is provided, with heating accomplished by steam generated in the HRSG.

In summary, the major features of the steam turbine cycle for this PFBC plant include the following:

- Subcritical steam conditions and single reheat (2400 psig/1050°F/1050°F).
- Motor-driven boiler feed pumps.
- Turbine configuration based on one 3,600 rpm tandem compound, two-flow exhaust machine.
- Condensate and feedwater heating principally accomplished in the HRSG, recovering heat from the gas turbine exhaust.

## 5.3 EMISSIONS PERFORMANCE

The operation of the circulating second-generation CPFBC is projected to result in low levels of emission for NOx, $SO_2$, and particulate (fly ash). At the same time, the discharge of solid wastes to a landfill or recycle process is expected to be comparable to that for a PC plant with a wet FGD system. The emissions levels are presented in Table 5-2.

The low level of $SO_2$ is achieved by capture of the sulfur in the bed by calcium in the limestone sorbent. The nominal design basis $SO_2$ removal rate is set at 95 percent with a Ca/S ratio of 1.75 for the CPFBC used in this study.

**Table 5-2**
**AIRBORNE EMISSIONS - CPFBC, CIRCULATING BED, SECOND GENERATION**

| | **Values at Design Condition (at 433 MWe)** | | | |
|---|---|---|---|---|
| | **lb/$10^6$ Btu** | **Tons/year 65%** | **Tons/year 85%** | **Tons/MWh** |
| $SO_2$ | 0.23 | 1,804 | 2,360 | 1.67 |
| NOx | 0.1 | 785 | 1,026 | 0.725 |
| Particulates | 0.002 | < 16 | <209 | 0.006 |
| $CO_2$ | 205.7 | 1,614,700 | 2,111,500 | 1,496 |

The low levels of NOx are achieved by the zoning and staging of combustion in the gas turbine MASB combustors. In addition, the limitation of bed gas exit temperature to 1600°F or less is a significant contributor to reducing the formation of NOx in the CPFBC vessel and the carbonizer, since the kinetics of NOx formation are significantly retarded at these relatively low combustion temperatures. The techniques of SCR or SNCR can reduce NOx emissions further, but are not applied to the subject plant in accordance with the ground rules stated in Section 3.

Particulate discharge to the atmosphere is limited by the use of the ceramic candle filters, which provide a collection efficiency of greater than 99.9 percent.

$CO_2$ emissions, on an intensive basis (lb/MMBtu), are comparable to other coal-fired technologies in this study since the same fuel is used (Illinois No. 6 coal).

## 5.4 DESCRIPTION OF CPFBC, SECOND GENERATION, ISLAND SYSTEMS

In this version of the circulating pressurized fluid-bed technology, crushed coal is injected, along with a sorbent such as limestone, into a carbonizer vessel. The coal is subjected to a mild gasification process, with the volatile matter driven off as overheads. This gaseous product passes through a single stage of cyclones to remove most of the particulates, followed by a ceramic candle filter. The hot gas from the CPFBC vessel also passes through a stage of cyclones, followed by a bank of candle filters. This gas and the low-Btu gas from the carbonizer are ducted to an MASB assembly, where the gas is combusted, and then expanded through the turbine section of the gas turbine.

The char from the carbonizer, along with the solids removed by the cyclone and filter, are passed to the CPFBC vessel where the char is combusted. The solids removed from the CPFBC overhead gases are collected in a hopper and passed into the FBHE, where they release sensible heat for steam generation. Additional steam generation, along with feedwater heating, occurs in the HRSG that is located in the gas turbine exhaust stream.

As noted in Section 5.4.2, the abundance of heat recovery opportunities in the CPFBC gas path results in a large reduction in steam flow normally extracted from the steam turbine for the purpose of feedwater heating. Therefore, the selection of the LP turbine configuration and last-stage bucket length will be indicative of a larger exhaust annulus area than might be expected for a steam turbine of comparable power output in a PC plant.

For this study, a combustion turbine based on the Westinghouse 501G technology class type has been selected. The actual machine would require some significant modifications to the standard production 501G unit. These are described in Section 5.4.3. This class of machine represents a good match to the overall cycle requirements, based on a total power output of a nominal 380 MWe. Operating in the boosted second-generation CPFBC cycle, the gas turbine is expected to generate approximately 207 MWe.

Based on the selection of a derivative of the 501G, the various components of this CPFBC plant may be sized, rated, etc. The text below describes each of the major components in a summary manner.

### 5.4.1 Carbonizer Subsystem

A single carbonizer subsystem is provided for the CPFBC package. The subsystem is comprised of a single carbonizer vessel, with two cyclones, two ceramic candle filter vessels, two collecting hoppers, and N-valves. Coal, limestone sorbent, and compressed air enter the carbonizer vessel from below via a manifold with multiple nozzles, one for each constituent. The coal is devolatilized and pyrolized in the carbonizer, with the low-Btu gas leaving as overheads and the char draining by gravity from a standpipe bed drain to a collecting hopper below. The overhead gases pass through the cyclones and ceramic candle filters with the collected solids drained to the collecting hoppers. The cleaned gases are conveyed to the gas turbine for combustion.

The carbonizer and its companion vessels are fabricated of SA-516 Gr. 70 steel plate, and are ASME Section VIII stamped vessels. The vessels are lined with refractory material 8 inches thick. Table 5-3 presents nominal dimensions and metal wall thicknesses for each vessel.

**Table 5-3**
**CARBONIZER VESSEL SIZE**

| Vessel | OD, ft-in. | Overall Height, ft | Twall, in.* |
|---|---|---|---|
| Carbonizer | 16-6 | 50 | 1.875 |
| Cyclone | 9-0 | 30 | 1.25 |
| Collecting Hopper | 14-0 | 20 | 1.625 |
| Ceramic Candle Filter | 11-0 | 50 | 1.25 |

*Nominal wall thickness at thickest section

The N-valve is a non-mechanical valve that uses nitrogen to fluidize and transfer solids from the carbonizer subsystem to the CPFBC. The valve is fabricated from carbon steel pipe segments, with nominal diameters of 30 inches.

### 5.4.2 Circulating Pressurized Fluid-Bed Combustor (CPFBC) Subsystem

The CPFBC subsystem is comprised of the CPFBC vessel, four cyclones, six ceramic candle filters, an FBHE, a pressure vessel containing the FBHE, and a J-valve.

The solids received from the carbonizer subsystem enter the CPFBC near the bottom of the vessel. Compressed air enters the vessel at two principal locations: primary air enters at the bottom of the vessel, with secondary air entering via an array of nozzles approximately 20 feet above a grid plate located near the bottom of the vessel. The grid plate functions as an air distributor and as a floor for the bed.

Flue gases and entrained solids leave the CPFBC vessel via two refractory-lined nozzles at the top of the vessel and pass through the cyclones and candle filters. The entrained solids removed by the cyclones flow by gravity down to the FBHE. The cleaned gas leaving the filters flows to the gas turbine where it is mixed with the low-Btu fuel gas from the carbonizer to support combustion in the topping combustor of the turbine.

The FBHE is contained inside a large horizontal cylindrical pressure vessel. The FBHE is divided into three major cells: a center cell that receives solids from the cyclones, and two end cells that contain tube bundles for superheating and reheating steam from the steam turbine cycle. The solids circulate between the CPFBC, cyclones, and FBHE; they return to the CPFBC in a continuous cycle. The J-valve modulates the transfer of solids, consisting of ash, unburned carbon, and sorbent material, from the bottom of the FBHE to the CPFBC vessel.

The ceramic candle filters are vertical, cylindrical vessels, with conical bottom sections, containing a number of ceramic candle elements. These candle elements are arranged into arrays, each containing a number of candle elements. The arrays are supported inside the vessel by a plenum and tubesheet arrangement, reinforced with channels. The vessel interior is lined with 8 inches of refractory. The filters are designed to provide a collection efficiency greater than 99.9 percent.

The CPFBC and its companion vessels are fabricated from SA-516 Gr. 70 steel plate material, and are ASME Section VIII stamped vessels. The vessels are lined with refractory material 8 inches thick. Table 5-4 presents approximate dimensional data for these vessels.

### 5.4.3 Gas Turbine Generator

The gas turbine generator selected for this repowering application is based on the Westinghouse Electric Corp. Type 501G. This machine is an axial flow, single spool, constant speed unit, with variable inlet guide vanes. The standard production version of this machine, fired with natural gas, will develop a compressor pressure ratio of 19.2:1 and a turbine inlet temperature of almost 2600°F.

**Table 5-4**
**CPFBC VESSEL SIZES**

| Vessel | OD, ft-in. | Overall Height, ft | Twall, in.* |
|---|---|---|---|
| PFBC | 22-0 | 115 | 2.375 |
| Cyclone | 11-0 | 41 | 1.375 |
| Filter | 11-0 | 50 | 1.25 |
| Hopper | 8-0 | 13 | 1.125 |
| FBHE Vessel | 36-0 | 55 (length) | 3.50 |

*Nominal wall thickness at thickest section

In second-generation CPFBC service, the machine must be modified to collect the compressor discharge air for discharge to the external CPFB circuit. The modifications to the machine include the incorporation of an MASB assembly to replace the original can-annular design. The MASB combustors burn the low-Btu gas with high efficiency while minimizing NOx production. The turbine nozzle area must be increased by approximately 2 percent to accommodate the increased mass flow of hot gas in this case. In addition, the rotor inlet temperature is reduced to 2470°F for this conceptual design case, to accommodate liner cooling considerations for the MASB assembly. Other modifications include rearranging the various auxiliary skids that support the machine to accommodate the spatial requirements. The generator is a standard hydrogen-cooled machine with static exciter.

### 5.4.4 <u>Boost Subsystem</u>

The boost subsystem is comprised of a single full-size boost compressor. A 12,000 hp 7,200V induction motor drives the fan through a hydroviscous type variable speed drive (VSD). The boost subsystem provides a boost in air pressure at the combustion turbine compressor discharge, which compensates for the additional unrecoverable pressure drop encountered in a CPFBC cycle. The pressure boost is instrumental in enabling the combustion turbine power output to meet or exceed its design basis power output potential, and to avoid significant changes to turbine design parameters.

The boost compressor is a centrifugal fan type unit placed in a heavy gauge housing with a stuffing box to minimize shaft seal leakage. The fan and housing are fabricated of carbon steel (A36 for the housing and A514 for the wheel). The VSD provides the capability to reduce compressor flow (by reducing speed) to match the airflow requirements of the combustion turbine compressor, which will vary at part load. Variable inlet guide vane control for the fans is possible, but potential air leakage problems around the guide vane shaft seals render the VSD the design of choice for this conceptual study.

### 5.4.5 Heat Recovery Steam Generator

The HRSG is a drum-type, double-pressure design matched to the characteristics of the gas turbine exhaust gas when firing low-Btu gas, and to the steam conditions selected for the steam cycle. The HP drum produces steam at 2670 psig, which is superheated in the HRSG superheater to 930°F. The mid-pressure drum produces steam at 600 psia, which is superheated in the HRSG to 500°F. This mid-pressure steam is used for burner transition cooling in the gas turbine. Additional heat recovery from the gas turbine exhaust gas is accomplished by heating feedwater and condensate in economizer surface in the HRSG.

### 5.4.6 Fuel Preparation and Injection System

The fuel preparation and injection system receives crushed coal, sized at 3/4" x 0, from the coal handling system. The system interface is at the slide gate valves at the discharge of the new silos.

The fuel preparation and injection system is comprised of two complete crushing/drying subsystems, each rated at 140 tph. At this capacity, one subsystem operates about 20 hours per day, or both subsystems operate approximately 10 hours per day to crush and dry the quantity of coal required to sustain continuous plant operation. The crusher/dryer arrangement provides operational flexibility for the plant with respect to crushing and drying operations, and provides redundancy so that a single failure will not cause a plant shutdown.

Each subsystem is comprised of a roller mill type crusher, an iso-kinetic type separator, a main mill fan, a cyclone collector, an exhaust fan, and a baghouse type filter. The rough-sized (3/4" x 0) coal is fed from the discharge of the coal silo through a rotary feeder to the inlet of the mill. The coal is crushed to nominal 1/8-inch size. The crushed coal is exhausted from the mill through the iso-kinetic separator, conveyed by entrainment in a circulating flow of air, to the cyclone collector. The crushed coal is disentrained from the air stream in the cyclone collector, and discharged through a rotary valve to a crushed coal day bin. Each day bin discharges through slide gate valves to gravimetric type feeders. The feeders meter the crushed coal into a lock hopper system. Each lock hopper train is comprised of a storage injector and a primary injector; these lock hoppers are pressurized by compressed air from the solids feed boost compressor. The storage injectors discharge into the primary injectors, which discharge the coal into the pressurized carbonizer and CPFBC vessels.

A supply of hot gas at approximately 1100°F is taken from the discharge of the combustion turbine, and supplied to each crushing/drying subsystem. The temperature for the circulating airstream transporting the coal around the drying loop is maintained above the dew point of the gas, or approximately 250°F. The exhaust fan for each subsystem removes a fraction of the circulating stream on a continuous basis to maintain moisture levels nearly constant. The exhaust flow is passed through a baghouse filter to remove particulates, which are discharged to the crushed coal day bin. Filtered exhaust gas is discharged through local short stacks.

### 5.4.7 Sorbent Injection System

The sorbent injection system receives limestone sorbent that is ground to the correct size distribution by the sorbent handling and preparation system. The sorbent is crushed to nominal 1/8-inch size. The sorbent day bins discharge through slide gate valves into two parallel trains of lock hopper systems. Each lock hopper train is comprised of a storage injector and a primary injector; the lock hoppers are pressurized by compressed air from the solids feed boost compressor. The storage injectors discharge into the primary injectors, which discharge the limestone into the carbonizer.

### 5.4.8 Flare Stack

A flare stack is provided to dispose of combustible gases from the carbonizer during upset transients such as unit trip. The stack is self-supporting, carbon steel with refractory lining and pilot ignition.

## 5.5 PFBC SUPPORT SYSTEMS (BALANCE OF PLANT)

### 5.5.1 Coal Handling System

The function of the coal handling system is to unload, convey, prepare, and store the coal delivered to the plant. The scope of the system is from the trestle bottom dumper and coal receiving hoppers up to and including the slide gate valves on the outlet of the coal storage silos.

Operation Description

The bituminous coal is delivered to the site by unit trains of 100-ton rail cars. Each unit train consists of 100, 100-ton rail cars. The unloading will be done by a trestle bottom dumper, which unloads the coal to two receiving hoppers. Coal from each hopper is fed directly into a vibratory feeder. The 6" x 0 coal from the feeder is discharged onto a belt conveyor (No. 1). The coal is then transferred to a conveyor (No. 2) that transfers the coal to the reclaim area. The conveyor passes under a magnetic plate separator to remove tramp iron, and then to the reclaim pile.

Coal from the reclaim pile is fed by two vibratory feeders, located under the pile, onto a belt conveyor (No. 3) that transfers the coal to the coal surge bin located in the crusher tower. The coal is reduced in size to 3" x 0. The coal then enters a second crusher that reduces the coal size to 1" x 0. The coal is then transferred by conveyor No. 4 to the transfer tower. In the transfer tower the coal is routed to the tripper that loads the coal into one of the two silos.

Technical Requirements and Design Basis

- Coal burn rate:
  - Maximum coal burn rate = 236,260 lb/h = 118.1 tph plus 10% margin = 130 tph (based on the 100% MCR rating for the plant, plus 10% design margin)
  - Average coal burn rate = 200,000 lb/h = 100 tph (based on MCR rate multiplied by an 85% capacity factor)

- Coal delivered to the plant by unit trains:
  - Two and one-half unit trains per week at maximum burn rate
  - Two unit trains per week at average burn rate
  - Each unit train shall have 10,000 tons (100-ton cars) capacity
  - Unloading rate = 9 cars/hour (maximum)
  - Total unloading time per unit train = 11 hours (minimum)
  - Conveying rate to storage piles = 900 tph (maximum, both conveyors in operation)
  - Reclaim rate = 300 tph
- Storage piles with liners, run-off collection, and treatment systems:
  - Active storage = 9,400 tons (72 hours at maximum burn rate)
  - Dead storage = 68,000 tons (30 days at average burn rate)

### 5.5.2 Limestone Handling and Preparation System

The function of the balance-of-plant limestone handling and preparation system is to receive, store, convey, and crush the limestone delivered to the plant for feeding to the CPFBC island sorbent injection system. The scope of the system is from the storage pile up to the sorbent injection system lock hopper inlets.

Operation Description

Limestone will be delivered to the plant by 25-ton trucks.

The limestone is unloaded onto a storage pile located adjacent to a reclaim hopper, beneath which are a pair of vibrating feeders, rated at 150 tons/hour each. A bulldozer pushes the limestone into the reclaim hopper, where a pair of feeders loads limestone onto a belt conveyor for transport to two 100 percent capacity equipment trains for crushing. Each train is comprised of a 120-ton capacity surge bin supplying one rod mill of 35 tons/hour capacity each. The rod mills discharge to the suction side of a positive displacement solids pump, which transport the pulverized material to two day bins of 265 tons capacity each. The day bins discharge the material to the sorbent injection system described in Section 5.4.7.

Technical Requirements and Design Basis

- Limestone usage rate:
  - Maximum limestone usage rate = 40,285 lb/h = 20.1 tph plus 10% margin = 22.2 tph (based on the 100% MCR rating for the plant)
  - Average limestone usage rate = 34,300 lb/h = 17 tph (based on the MCR limestone usage rate multiplied by an 85% capacity factor)
- Limestone delivered to the plant by 25-ton dump trucks
- Total number of trucks per day = 21 (based on maximum usage rate)
- Total truck unloading time per day = 4 hours
- Unloading time per truck = 10 minutes
- Receiving hopper capacity = 35 tons
- Limestone received = 1" x 0
- Limestone storage capacity = 16,000 tons (30 days supply at maximum burn rate)
- Storage pile size = 185 ft x 90 ft x 40 ft high
- Conveying rate to surge bin = 150 tph
- Vibratory feeder/limestone rod mill capacity, 35 tph for each mill (based on two mills operating one shift per day or one mill operating two shifts per day)
- Day bin storage = 500 tons (24-hour supply at maximum burn rate, total for two bins)

### 5.5.3 Ash Handling

The ash handling system conveys, stores, and disposes of ash removed from the fluidized bed (spent bed material, or bottom ash), and from the ceramic candle filters (fly ash).

Spent bed material drains from the FBHE bed into a restricted pipe discharge (RPD) hopper. The hopper operates at atmospheric pressure; the pressure drop from the FBHE vessel to atmospheric pressure occurs across the packed bed material in the restricted inside diameter (nominally 6 inches) of the refractory-lined pipe. The pipe extends downward approximately 8'-6" into the hopper.

A slide gate valve at the bottom outlet of the hopper regulates the flow of material from the hopper to a screw cooler, which cools and transports the ash out and onto a system of drag chain conveyors. The conveyors transport the ash to a pair of storage silos for temporary holdup. Ash from the candle filters is transported from the RPD hoppers located at the base of the filters. A slide gate at the bottom outlet of the hopper regulates the flow of material from the hopper to a screw cooler, which cools and transports the ash to a system of drag conveyors.

The silos are sized for a nominal holdup capacity of 36 hours of full-load operation (1,140 tons capacity) per each. At periodic intervals, a convoy of ash hauling trucks will transit the unloading station underneath the silos and remove a quantity of ash for disposal. Approximately 30 truck loads per day are required to remove the total quantity of ash produced by the repowered plant operating at nominal rated power.

## 5.6 STEAM CYCLE BALANCE OF PLANT

The following section provides a description of the steam turbines and their auxiliaries.

### 5.6.1 Steam Turbine Generator and Auxiliaries

The steam turbine consists of a high-pressure (HP) section, intermediate-pressure (IP) section, and one double-flow low-pressure (LP) section, all connected to the generator by a common shaft. The HP and IP sections are contained in a single span, opposed-flow casing, with the double-flow LP section in a separate casing. The LP turbine has a last-stage bucket length of 30 inches.

Main steam from the HRSG and gasifier island is combined in a header, and then passes through the stop valves and control valves and enters the turbine at 2400 psig/1050°F. The steam initially enters the turbine near the middle of the high-pressure span, flows through the turbine, and returns to the FBHE for reheating. The reheat steam flows through the reheat stop valves and intercept valves and enters the IP section at 460 psig/1050°F. After passing through the IP section, the steam enters a cross-over pipe, which transports the steam to the LP section. The steam divides into two paths and flows through the LP sections exhausting downward into the condenser.

Turbine bearings are lubricated by a closed-loop water-cooled pressurized oil system. The oil is contained in a reservoir located below the turbine floor. During startup or unit trip the oil is pumped by an emergency oil pump mounted on the reservoir. When the turbine reaches 95 percent of synchronous speed, oil is pumped by the main pump mounted on the turbine shaft. The oil flows through water-cooled heat exchangers prior to entering the bearings. The oil then flows through the bearings and returns by gravity to the lube oil reservoir.

Turbine shafts are sealed against air in-leakage or steam blowout using a modern positive pressure variable clearance shaft sealing design arrangement connected to a low-pressure steam seal system. During startup, seal steam is provided from the main steam line. As the unit increases load, HP turbine gland leakage provides the seal steam. Pressure regulating valves control the gland header pressure and dump any excess steam to the condenser. A steam packing exhauster maintains a vacuum at the outer gland seals to prevent leakage of steam into the turbine room. Any steam collected is condensed in the packing exhauster and returned to the condensate system.

The generator is a hydrogen-cooled synchronous type, generating power at 23 kV. A static, transformer type exciter is provided.

The generator is cooled with a hydrogen gas recirculation system using fans mounted on the generator rotor shaft. The heat absorbed by the gas is removed as it passes over finned tube gas coolers mounted in the stator frame. Gas is prevented from escaping at the rotor shafts by a closed-loop oil seal system. The oil seal system consists of a storage tank, pumps, filters, and pressure controls, all skid-mounted.

The steam turbine generator is controlled by a triple redundant microprocessor-based electro-hydraulic control system. The system provides digital control of the unit in accordance with programmed control algorithms, color CRT operator interfacing, datalink interfaces to the balance-of-plant distributed control system (DCS), and incorporates on-line repair capability.

### 5.6.2 Condensate and Feedwater Systems

Condensate

The function of the condensate system is to pump condensate from the condenser hotwell to the deaerator, through the gland steam condenser, and the feedwater heater. The system consists of one main condenser; two 50 percent capacity, motor-driven vertical condensate pumps; one gland steam condenser, and a low-temperature feedwater heater. Condensate is delivered to a common discharge header through two separate pump discharge lines, each with a check valve and a gate valve. A common minimum flow recirculation line discharging to the condenser is provided to maintain minimum flow requirements for the gland steam condenser and the condensate pumps.

Feedwater

The function of the feedwater system is to pump the various feedwater streams from the deaerator storage tank to the respective steam drums. Two motor-driven, half-sized boiler feed pumps are provided. At least one of the two pumps is provided with a variable speed drive to support startup, shutdown, and part-load operation. Each pump is provided with inlet and outlet isolation valves, outlet check valves, and individual minimum flow recirculation lines discharging back to the deaerator storage tank. The recirculation flow is controlled by pneumatic flow control valves. In addition, the suctions of the boiler feed pumps are equipped with startup strainers.

### 5.6.3 Main and Reheat Steam Systems

Main and Reheat Steam

The function of the main steam system is to convey main steam from the FBHE superheater outlet to the high-pressure turbine stop valves. The function of the reheat system is to convey steam from the HP turbine exhaust to the FBHE reheater, and to the turbine reheat stop valves.

Main steam at approximately 2500 psig/1050°F exits the FBHE superheater through a motor-operated stop/check valve and a motor-operated gate valve, and is routed to the HP turbine.

Cold reheat steam at approximately 510 psig/660°F exits the HP turbine, flows through a motor-operated isolation gate valve, to the FBHE reheater. Hot reheat steam at approximately 460 psig/1050°F exits the FBHE reheater through a motor-operated gate valve and is routed to the IP turbines.

### 5.6.4 Circulating Water System

The function of the circulating water system is to supply cooling water to condense the main turbine exhaust steam. The system consists of two 50 percent capacity, vertical circulating water pumps; a mechanical draft evaporative cooling tower, and carbon steel cement-lined interconnecting piping. The condenser is a single-pass, horizontal type with divided water boxes. There are two separate circulating water circuits in each box. One-half of the condenser can be removed from service for cleaning or plugging tubes. This can be done during normal operation at reduced load.

### 5.6.5 Major Gas Path and Steam Cycle Piping Required

A significant amount of high-temperature/high-pressure piping is required to connect the various components comprising the gas path and steam cycle. A summary of the required piping is presented in Table 5-5 and Table 5-6.

## 5.7 ACCESSORY ELECTRIC PLANT

The accessory electric plant consists of all switchgear and control equipment, generator equipment, station service equipment, conduit and cable trays, all wire and cable. It also includes the main power transformer, all required foundations, and standby equipment.

**Table 5-5**
**CPFBC - STEAM CYCLE PIPING REQUIRED**

| Pipeline | Flow, lb/h | Press., psig | Temp., °F | Material | OD, in. | Twall, in. |
|---|---|---|---|---|---|---|
| Condensate | 1,049,800 | 125 | 110 | A106 Gr. B | 12 | Sch. 40 |
| Feed Pump to HRSG | 1,037,500 | 2980 | 260 | A106 Gr. C | 10 | Sch. 160 |
| Feedwater/HRSG to FBHE | 689,800 | 2700 | 680 | A106 Gr. C | 8 | Sch. 160 |
| Main Steam/HRSG to FBHE | 347,614 | 2600 | 930 | A335 Gr. P22 | 10 | 1.50 |
| Main Steam/FBHE to Steam Turbine | 1,037,500 | 2500 | 1050 | A335 Gr. P22 | 14 | 2.0 |
| Cold Reheat | 991,300 | 510 | 620 | A106 Gr. B | 28 | 0.50 |
| Hot Reheat | 1,057,300 | 460 | 1050 | A691 Gr. 22 | 28 | 0.75 |

**Table 5-6**
**CPFBC - GAS PATH PIPING REQUIRED**

| Pipeline | Flow, lb/h | Press., psig | Temp., °F | Material | OD, in. | Twall, in. |
|---|---|---|---|---|---|---|
| Gas Turbine Compressor to Boost Compressor | 2,253,786 | 300 | 800 | A691 Gr. P22 | 42 | 0.50 |
| Boost Compressor to CPFBC | 2,253,786 | 300 | 830 | A691 Gr. P22 | 42 | 0.50 |
| CPFBC Island to Gas Turbine (Vitiated Air) | 1,870,247 | 260 | 1400 | A672 Gr. B70 Refractory-lined | 78 | 0.75 |
| Low-Btu Gas to Gas Turbine (from Carbonizer) | 612,830 | 310 | 1400 | A672 Gr. B70 Refractory-lined | 36 | 0.375 |
| Carbonizer Compressed Air | 381,207 | 320 | 890 | A106 Gr. B | 16 | Sch. 40 |
| Transport Compressed Air | 198,371 | 350 | 150 | A106 Gr. B | 8 | Sch. 40 |

## 5.8 INSTRUMENTATION AND CONTROL

An integrated plant-wide control and monitoring system (DCS) is provided. The DCS is a redundant microprocessor-based, functionally distributed system. The control room houses an array of multiple video monitor (CRT) and keyboard units. The CRT/keyboard units are the primary interface between the generating process and operations personnel. The DCS incorporates plant monitoring and control functions for all the major plant equipment. The DCS is designed to provide 99.5 percent availability. The plant equipment and the DCS are designed for automatic response to load changes from minimum load to 100 percent. Startup and shutdown routines are implemented as supervised manual with operator selection of modular automation routines available.

## 5.9 SITE, STRUCTURES, AND SYSTEMS INTEGRATION

### 5.9.1 Plant Site and Ambient Design Conditions

Refer to Section 2 for a description of the plant site and ambient design conditions.

### 5.9.2 New Structures and Systems Integration

The development of the reference plant site to incorporate the structures required for this technology is based on the assumption of a flat site. The general layout is shown in Figure 5-2. The CPFBC island and related structures are arranged in a cluster, with the coal and slurry preparation facilities adjacent to the east.

The gas turbine and its ancillary equipment are sited directly to the north of the CPFBC island in a turbine building. The HRSG and stack are north of the gas turbine, with the steam turbine and its generator in a separate building located to the west. Service and administration building are located at the west side of the steam turbine building.

NOTES:

DD

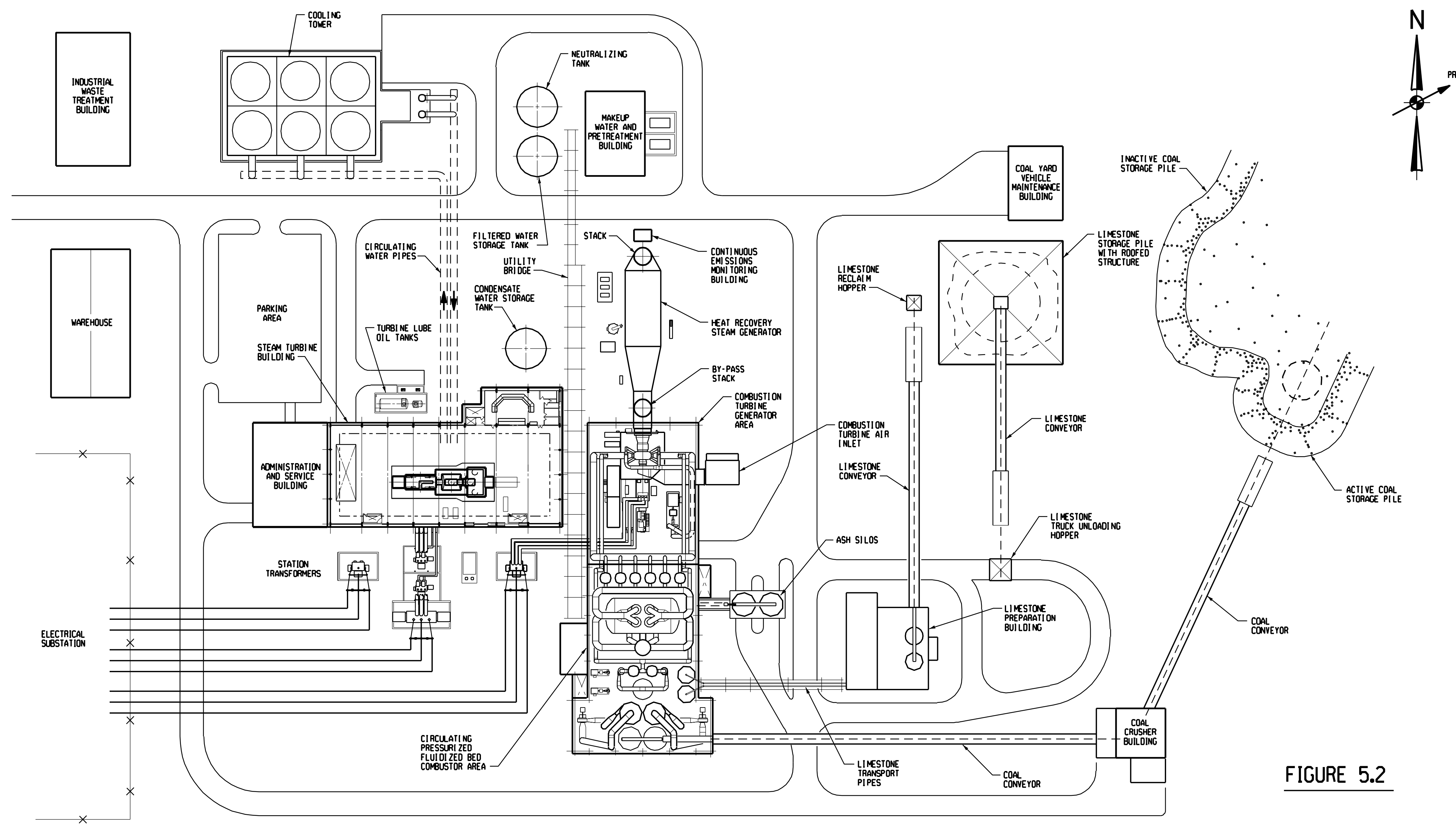


FIGURE 5.2

PLAN VIEW

0 50 100 150 200
GRAPHIC SCALE IN FEET

| REV | DATE | DESCRIPTION | DRAWN | CHECKED | LEAD DESIGNER ENGINEER | LEAD DISCP ENGINEER | PROJ ENGR MANAGER | PROJECT MANAGER |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

| STATUS OF DRAWING | DEFINITION | CONSTRUCTION STATUS |
|---|---|---|
| PRELIMINARY | REPRESENTS GENERAL DESIGN CONCEPTS BASED ON ASSUMPTIONS. REVIEWED NOT CHECKED. | |

LDE ___ DATE ___

DRAWN BY CLR DATE 12/21/98

CHECKED BY DATE

LEAD DESIGNER DATE

ENGINEER DATE

LEAD DISCIPLINE ENGR. DATE

ORIGINALLY PREPARED UNDER THE RESPONSIBLE SUPERVISION OF
PE: ___ STATE: ___
LIC. NO.: ___ DATE: ___

PROJECT ENGINEERING MANAGER

PROJECT MANAGER

PARSONS
PARSONS ENERGY & CHEMICALS GROUP INC.
READING OFFICE

CLIENT/PROJECT TITLE
CLEAN COAL TECHNOLOGY PROGRAM
CIRC PRESSUREIZED FLUIDIZED BED COMB
DEPARTMENT OF ENERGY TASK 22

PLANT GENERAL ARRANGEMENT
PLANT LAYOUT

SCALE 1"=50'

PARSON'S DWG. NO. 8436-1-200-002-701

REV A

| | ARCH | HVAC | I & C | ELECT | MECH | CIVIL | STRUC |
|---|---|---|---|---|---|---|---|
| -- | --- | --- | --- | --- | --- | --- | --- |

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PPGI-DATE:

**Reserved for the reverse side of Figure 5-2 (11x17)**

The cooling tower heat sink for the steam turbine is located to the north of the steam turbine building. The electrical transformer area, containing the main step-up transformers for the gas turbine and steam turbine, as well as the unit auxiliary transformer, is south of the steam turbine building. The plant electrical switchyard is west of the transformers.

The arrangement described above provides good alignment and positioning for major interfaces, relatively short steam, feedwater, and circulating water gas pipelines, and allows good access for vehicular traffic. Transmission line access from the gas turbine and steam turbine step-up transformer to the switchyard is also maintained at short distances.

The air and gas path is developed in a short and direct manner, with ambient air entering an inlet filter/silencer located east of the gas turbine. The clean, hot, medium-Btu gas is conveyed to the turbine combustors for mixing with the air that remained on-board the machine. Turbine exhaust is ducted directly through a triple-pressure HRSG and then to a new 213-foot stack. The height of the stack is established by application of a good engineering practice rule from 40 CFR 51.00.

Access and construction laydown space are freely available on the periphery of the plant, with several roads, 26 feet wide plus shoulders, running from north to south between the various portions of the plant.

## 5.10 EQUIPMENT LIST

### ACCOUNT 1 COAL AND SORBENT HANDLING

### ACCOUNT 1A COAL RECEIVING AND HANDLING

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Bottom Trestle Dumper and Receiving Hoppers | N/A | 200 ton | 2 |
| 2 | Feeder | Vibratory | 450 tph | 2 |
| 3 | Conveyor No. 1 | 54" belt | 900 tph | 1 |
| 4 | As-Received Coal Sampling System | Two-stage | N/A | 1 |
| 5 | Conveyor No. 2 | 54" belt | 900 tph | 1 |
| 6 | Reclaim Hopper | N/A | 40 ton | 2 |
| 7 | Feeder | Vibratory | 200 tph | 2 |
| 8 | Conveyor No. 3 | 48" belt | 400 tph | 1 |
| 9 | Crusher Tower | N/A | 400 tph | 1 |
| 10 | Coal Surge Bin w/Vent Filter | Compartment | 400 ton | 1 |
| 11 | Crusher | Granulator reduction | 6"x0 - 3"x0 | 1 |
| 12 | Crusher | Impactor reduction | 3"x0 - 1¼"x0 | 1 |
| 13 | As-Fired Coal Sampling System | Swing hammer | | 2 |
| 14 | Conveyor No. 4 | 48" belt | 300 tph | 1 |
| 15 | Transfer Tower | N/A | 300 tph | 1 |
| 16 | Tripper | N/A | 300 tph | 1 |
| 17 | Coal Silo w/Vent Filter and Slide Gates | N/A | 1,300 ton | 2 |

**ACCOUNT 1B LIMESTONE HANDLING AND PREPARATION SYSTEM**

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Truck Unloading Hopper | N/A | 35 ton | 2 |
| 2 | Feeder | Vibratory | 150 tph | 2 |
| 3 | Conveyor No. 1 | 30" belt | 150 tph | 1 |
| 4 | Conveyor No. 2 | 30" belt | 150 tph | 1 |
| 5 | Limestone Surge Bin | | 120 ton | 2 |
| 6 | Bin Activator | | 35 tph | 2 |
| 7 | Feeder | Gravimetric | 35 tph | 2 |
| 8 | Limestone Rod Mill | Rotary | 35 tph | 2 |
| 9 | Pump | Screw type, pneumatic; Fuller-Kovako | 35 tph | 2 |
| 10 | Blower | Positive displacement | 15 psig | 2 |
| 11 | Dust Collector | Bag filter | | 2 |
| 12 | Exhaust Fan | Centrifugal | | 2 |
| 13 | Limestone Day Bin | | 24 hours/265 tons | 2 |
| 14 | Slide Gate Valve | | | 2 |

## ACCOUNT 2 COAL AND SORBENT PREPARATION AND FEED

### ACCOUNT 2A FUEL PREPARATION AND FUEL INJECTION

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Feeder | Rotary | 140 tph | 2 |
| 2 | Grinding Mill | Roller | 140 tph | 2 |
| 3 | Separator | Iso-kinetic | 140 tph | 2 |
| 4 | Cyclone Collector | Cone bottom | 140 tph | 2 |
| 5 | Cyclone Rotary Valve | | 120 tph | 2 |
| 6 | Dust Collector | High efficiency fabric | 30,000 cfm | 2 |
| 7 | Dust Collector Rotary Valve | | 10 tph | 2 |
| 8 | Exhaust Fan | Centrifugal | 30,000 cfm | 2 |
| 9 | Main Mill Fan | Centrifugal | 120,000 cfm | 2 |
| 10 | Crushed Coal Bin | Vertical, cylindrical | 640 ton | 2 |
| 11 | Slide Gate Valve | | 100 tph | 2 |
| 12 | Feeders | Gravimetric | 100 tph | 2 |
| 13 | Coal Storage Injector | Vertical, cylindrical | 11'-0" ID x 27'-0" | 2 |
| 14 | Coal Primary Injector | Vertical, cylindrical | 12'-0" ID x 61'-6" | 2 |

### ACCOUNT 2B SORBENT INJECTION

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Limestone Storage Injector | Vertical, cylindrical | | 2 |
| 2 | Limestone Primary Injector | Vertical, cylindrical | | 2 |
| 3 | Feed Valve | Rotary | | 2 |

## ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

## ACCOUNT 3A CONDENSATE AND FEEDWATER SYSTEM

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Cond. Storage Tank | Vertical, cyl., outdoor | 100,000 gal | 1 |
| 2 | Condensate Pumps | Vert. canned | 1,050 gpm @ 400 ft | 2 |
| 3 | LP Feedwater Heater 1 | Horiz. U tube | 2,010 gpm 110°F to 180°F | 1 |
| 4 | Deaerator | Horiz. spray type | 1,006,100 lb/h 180°F to 240°F | 1 |
| 5 | Deaearator Storage Tank | Horiz. pressure vessel | 60,000 gal 80 psig | 1 |
| 6 | Boiler Feed Pumps | Barrel type, multi-staged, centr. | 1,040 gpm @ 6,800 ft | 2 |
| 7 | GT Cooling Water Pump | Barrel type, multi-staged, centr. | 70 gpm @ 1,500 ft | 2 |

**ACCOUNT 3B MISCELLANEOUS EQUIPMENT**

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Auxiliary Boiler (Heating) | Shop fab. water tube design | 125 psig, sat, 80,000 lb/h | 1 |
| 2 | Fuel Oil Storage Tank | Vertical, cylindrical | 60,000 gal | 1 |
| 3 | Fuel Oil Unloading Pump | Gear | 50 psig, 100 gpm | 1 |
| 4 | Fuel Oil Supply Pump | Gear | 150 psig, 50 gpm | 2 |
| 5 | Service Air Compressors | Recip., single stage, double acting, horiz. | 100 psig, 450 cfm | 2 |
| 6 | Inst. Air Dryers | Duplex, regenerative | 450 cfm | 1 |
| 7 | Service Water Pumps | Horiz. centrifugal, double suction | 200 ft, 700 gpm | 2 |
| 8 | Closed Cycle Cooling Heat Exchanger | Shell and tube | 50% cap. each | 2 |
| 9 | Closed Cycle Cooling Water Pumps | Horizontal, centrifugal | 70 ft, 700 gpm | 2 |
| 11 | Fire Service Booster Pump | Two-stage horiz. cent. | 250 ft, 700 gpm | 1 |
| 12 | Engine-Driven Fire Pump | Vert. turbine, diesel engine | 350 ft, 1,000 gpm | 1 |
| 13 | Raw Water | SS, single suction | 60 ft, 1,500 gpm | 2 |
| 14 | Filtered Water Pumps | SS, single suction | 160 ft, 120 gpm | 2 |
| 15 | Filtered Water Tank | Vertical, cylindrical | 100,000 gal | 1 |
| 16 | Makeup Demineralizer | Anion, cation, and mixed bed | 200 gpm | 2 |
| 17 | Liquid Waste Treatment System | | 10 years, 25-hour storm | 1 |
| 18 | Condensate Demineralizer | Mixed bed | 1,200 gpm | 2 |

## ACCOUNT 4 PFBC BOILER AND ACCESSORIES

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Carbonizer Vessel | Vertical, cyl., refractory lined, steel, ASME VIII | 300 psig | 1 |
| 2 | Carbonizer Cyclone | | 306,000 lb/h gas flow ea. | 2 |
| 3 | Carbonizer Cyclone Collecting Hopper | | | 2 |
| 4 | Carbonizer Filter | Ceramic candle | 306,000 lb/h gas flow ea. | 2 |
| 5 | Carbonizer Boost Compressor | Centrifugal, high press./high temp. housing | 9,000 acfm housing design: 400 psig/1000°F | 2 |
| 6 | CPFBC Vessel | Vertical, cyl., refractory lined, steel | 300 psig | 1 |
| 7 | CPFBC Cyclone | Centrifugal | 467,560 lb/h ea. | 4 |
| 8 | CPFBC Filter | Ceramic candle | 311,700 lb/h gas flow ea. | 6 |
| 9 | Fluid-Bed Heat Exchanger Pressure Vessel | Horizontal cylindrical pressure vessel, steel, ASME VIII | 300 psig | 1 |
| 10 | Fluid-Bed Heat Exchanger | Fin-tube, waterwall, multi-cell fabrication contains steam generation bed and drum; super-heater, and reheater sections | Main steam:<br>2500 psig/1050°F<br>Reheat steam<br>525 psig/1050°F | 1 |
| 11 | Refractory-Lined Pipe | Carbon steel, B31.1 Code, 6-inch refractory lining | 300 psig/1600°F gas | |
| 12 | Circulation Pumps | Canned, vertical | 10,000 gpm/60 ft TDH<br>Design pressure 2200 psig | 1 |
| 13 | Flare Stack | Vertical stack, refractory lined | 84 in. OD, 55 ft high | 1 |
| 14 | Solids Feed Booster Compressor | Centrifugal high press./high temp. housing | 1800 acfm housing design: 300 psig/100°F | 2 |
| 15 | Filter Backpulse Compressor | Positive displacement gas compressor, multi-stage, intercooled | Inlet 210 psig/100°F<br>Outlet 1500 psig/150°F | 2 |

## ACCOUNT 5 FLUE GAS CLEANUP

(Not required, cleanup accomplished in ceramic filters, Account No. 4)

## ACCOUNT 6 COMBUSTION TURBINE AND AUXILIARIES

## ACCOUNT 6A COMBUSTION TURBINE AND ACCESSORIES

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | 210 MWe Gas Turbine Generator | Axial flow single spool based on W501G | 1120 lb/sec airflow<br>2580°F firing temp.<br>19.2:1 pressure ratio | 1 |
| 2 | Enclosure | Sound attenuating | 85 db at 3 ft outside the enclosure | 1 |
| 3 | Air Inlet Filter/Silencer | Two-stage | 1120 lb/sec airflow<br>3.0 in. $H_2O$ pressure drop, dirty | 1 |
| 4 | Starting Package | Electric motor, torque Converter drive, turning gear | 2,500 hp, time from turning gear to full load ~30 minutes | 1 |
| 5 | Air to Air Cooler | | | 1 |
| 6 | Mechanical Package | CS oil reservoir and pumps dual vertical cartridge filters air compressor | | 1 |
| 7 | Oil Cooler | Air-cooled, fin fan | | 1 |
| 8 | Electrical Control Package | Distributed control system | 1 sec. update time/<br>8 MHz clock speed | 1 |
| 9 | Generator Glycol Cooler | Air-cooled, fin fan | | 1 |
| 10 | Compressor Wash Skid | | | 1 |
| 11 | Fire Protection Package | Halon | | 1 |

## ACCOUNT 6B BOOST SUBSYSTEM

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Main Booster Compressor | Centrifugal, high press./high temp. housing, variable speed drive | 60,000 acfm, housing design: 300 psig/240°F | 1 |

## ACCOUNT 7 WASTE HEAT BOILER, DUCTING, AND STACK

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Heat Recovery Steam Generator | Drum, double pressure, includes economizer section | 2700 psig/930°F/675°F 1,037,500 lb/h 600 psig/500°F, 66,000 lb/h | 1 |
| 2 | Stack | Carbon steel plate type 409 stainless steel lined | 60 ft/sec exit velocity 213 ft high by 21 ft inside dia. | 1 |

## ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

| Equipment No. | Description | Type | Design Condition (per each) | Qty |
|---|---|---|---|---|
| 1 | 200 MW Turbine Generator | TC2F30 | 2400 psig 1050°F/1050°F | 1 |
| 2 | Bearing Lube Oil Coolers | Shell and tube | | 2 |
| 3 | Bearing Lube Oil Conditioner | Pressure filter closed loop | | 1 |
| 4 | Control System | Electro-hydraulic | 1600 psig | 1 |
| 5 | Generator Coolers | Plate and frame | | 2 |
| 6 | Hydrogen Seal Oil System | Closed loop | | 1 |
| 7 | Surface Condenser | Single pass, divided waterbox | 1,049,800 lb/h steam @ 2.5 in. Hga with 75°F water, 20°F temp. rise | 1 |
| 8 | Condenser Air Ejector | Twin element, two-stage, condensing ejector, motivated by steam | 240 lb/h air and non-condensibles @ 2.0 in. Hga | 1 |
| 9 | Hogging Ejector | Single element, single-stage ejector, air motivated | 425 cfm @ 10 in. Hga | 1 |

## ACCOUNT 9 COOLING WATER SYSTEM

| Equipment No. | Description | Type | Design Condition (per each) | Qty |
|---|---|---|---|---|
| 1 | Circ. W. Pumps | Vert. wet pit | 50,000 gpm @ 60 ft | 2 |
| 2 | Cooling Tower | Evaporative, mechanical draft | 54°F WB 20°F approach 20°F range 100,000 gpm | 1 |

## ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

| Equipment No. | Description | Type | Design Condition | Qty |
|---|---|---|---|---|
| 1 | Fluidized Bed Heat Exchanger RPD Hoppers | Restricted pipe discharge, refractory lined | 300 psig | 2 |
| 2 | Ceramic Candle Filter RPD Hoppers | Restricted pipe discharge, refractory lined | 300 psig | 2 |
| 3 | Ash Screw Coolers (Spent Bed) | Water cooled | 50,000 lb/h | 1 |
| 4 | Ash Screw Coolers (Candle Filter) | Water cooled | 15,000 lb/h | 1 |
| 5 | Drag Chain Conveyor | | 65,000 lb/h | 1 |
| 6 | Drag Chain Conveyor | | 65,000 lb/h | 1 |
| 7 | Drag Chain Conveyor | | 71,000 lb/h | 1 |
| 8 | Ash Storage Silo | Vertical, cylindrical, concrete | 1,140 ton | 2 |
| 9 | Fluidizing Blower | | | 2 |
| 10 | Telescoping Chute | | | 2 |

## 5.11 CONCEPTUAL CAPITAL COST ESTIMATE SUMMARY

The summary of the conceptual capital cost estimate for the CPFBC plant is shown in Table 5-7. The estimate summarizes the detail estimate values that were developed consistent with Section 9, "Capital and Production Cost and Economic Analysis." The detail estimate results are contained in Appendix E.

Examination of the values in the table reveal several relationships that are subsequently addressed. The relationship of the equipment cost to the direct labor cost varies for each account. This variation is due to many factors including the level of fabrication performed prior to delivery to the site, the amount of bulk materials represented in the equipment or material cost column, and the cost basis for the specific equipment (degree of field fabrication required for items too large to ship to the site in one or several major pieces). Also note that the total plant cost ($/kW) values are all determined on the basis of the total plant net output. This will be more evident as other technologies are compared. One significant change compared to the PC technologies is that the power is generated by multiple sources. As a result, the steam turbine portions have a good economy of scale, but the combustion turbine and technology do not.

# Table 5-7

**Client:** DEPARTMENT OF ENERGY  **Report Date:** 14-Aug-98 10:52 AM
**Project:** Market Based Advanced Coal Power Systems

## TOTAL PLANT COST SUMMARY

**Case:** 2gPFBCw/Boost
**Plant Size:** 379.2 MW,net  **Estimate Type:** Conceptual  **Cost Base (Jan)** 1998 ($x1000)

| Acct No. | Item/Description | Equipment Cost | Material Cost | Labor Direct | Labor Indirect | Sales Tax | Bare Erected Cost $ | Eng'g CM H.O.& Fee | Contingencies Process | Contingencies Project | TOTAL PLANT COST $ | TOTAL PLANT COST $/kW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | COAL & SORBENT HANDLING | 7,538 | 1,270 | 3,245 | 227 | | **$12,280** | 982 | | 2,794 | **$16,056** | 42 |
| 2 | COAL & SORBENT PREP & FEED | 12,633 | 1,254 | 2,838 | 199 | | **$16,924** | 1,354 | 609 | 2,596 | **$21,483** | 57 |
| 3 | FEEDWATER & MISC. BOP SYSTEMS | 6,107 | 3,212 | 4,799 | 336 | | **$14,453** | 1,156 | | 3,709 | **$19,319** | 51 |
| 4 | CARBONIZER, PFBC & PFB HTX | | | | | | | | | | | |
| 4.1 | PFB PRESSURE VESSEL | 3,031 | | 448 | 31 | | **$3,510** | 281 | 526 | 432 | **$4,749** | 13 |
| 4.2 | PFBC Boiler | 1,672 | | 357 | 25 | | **$2,055** | 164 | 308 | 253 | **$2,780** | 7 |
| 4.3 | PFBC Economizer | 24,307 | | 4,599 | 322 | | **$29,227** | 2,338 | 4,384 | 3,595 | **$39,544** | 104 |
| 4.4-4.9 | Other PFBC Equipment | 1,092 | 6,241 | 4,082 | 286 | | **$11,701** | 936 | 68 | 2,566 | **$15,272** | 40 |
| | *SUBTOTAL 4* | *30,102* | *6,241* | *9,486* | *664* | | ***$46,493*** | *3,719* | *5,287* | *6,845* | ***$62,345*** | *164* |
| 5 | HOT GAS CLEANUP & PIPING | 15,015 | 4,968 | 4,582 | 321 | | **$24,886** | 1,991 | 4,270 | 6,259 | **$37,405** | 99 |
| 6 | COMBUSTION TURBINE/ACCESSORIES | | | | | | | | | | | |
| 6.1 | Combustion Turbine Generator | 50,976 | | 2,820 | 197 | | **$53,994** | 4,319 | 8,099 | 6,641 | **$73,053** | 193 |
| 6.2-6.9 | C.T. Booster Air System & BOA | 785 | 1,018 | 1,141 | 69 | | **$3,013** | 241 | | 707 | **$3,961** | 10 |
| | *SUBTOTAL 6* | *51,762* | *1,018* | *3,960* | *267* | | ***$57,006*** | *4,561* | *8,099* | *7,348* | ***$77,014*** | *203* |
| 7 | HRSG, DUCTING & STACK | | | | | | | | | | | |
| 7.1 | Heat Recovery Steam Generator | 7,241 | | 927 | 65 | | **$8,233** | 659 | | 889 | **$9,781** | 26 |
| 7.2-7.9 | HRSG Accessories, Ductwork and Stack | 1,528 | 611 | 1,136 | 80 | | **$3,355** | 268 | | 513 | **$4,136** | 11 |
| | *SUBTOTAL 7* | *8,769* | *611* | *2,063* | *144* | | ***$11,588*** | *927* | | *1,402* | ***$13,917*** | *37* |
| 8 | STEAM TURBINE GENERATOR | | | | | | | | | | | |
| 8.1 | Steam TG & Accessories | 17,120 | | 2,666 | 187 | | **$19,972** | 1,598 | | 2,157 | **$23,727** | 63 |
| 8.2-8.9 | Turbine Plant Auxiliaries and Steam Piping | 2,687 | 4,169 | 3,254 | 228 | | **$10,339** | 827 | | 1,874 | **$13,039** | 34 |
| | *SUBTOTAL 8* | *19,807* | *4,169* | *5,920* | *414* | | ***$30,311*** | *2,425* | | *4,031* | ***$36,767*** | *97* |
| 9 | COOLING WATER SYSTEM | 4,286 | 2,498 | 4,325 | 303 | | **$11,411** | 913 | | 2,237 | **$14,561** | 38 |
| 10 | ASH/SPENT SORBENT HANDLING SYS | 6,504 | 1,192 | 1,531 | 107 | | **$9,334** | 747 | 486 | 1,580 | **$12,147** | 32 |
| 11 | ACCESSORY ELECTRIC PLANT | 9,721 | 2,715 | 6,934 | 485 | | **$19,855** | 1,588 | | 3,503 | **$24,946** | 66 |
| 12 | INSTRUMENTATION & CONTROL | 5,319 | 1,439 | 5,507 | 385 | | **$12,650** | 1,012 | | 2,121 | **$15,783** | 42 |
| 13 | IMPROVEMENTS TO SITE | | 3,349 | 5,430 | 380 | | **$9,159** | 733 | | 2,967 | **$12,859** | 34 |
| 14 | BUILDINGS & STRUCTURES | | 4,635 | 6,006 | 420 | | **$11,061** | 885 | | 2,986 | **$14,932** | 39 |
| | **TOTAL COST** | **$177,562** | **$38,572** | **$66,624** | **$4,653** | | **$287,411** | **$22,993** | **$18,752** | **$50,379** | **$379,535** | **1001** |